



Natural Environment Research Council

BRITISH GEOLOGICAL SURVEY

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Mineral Reconnaissance Programme Report



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No. 75

**Geophysical surveys in part of
the Halkyn–Minera mining
district, north-east Wales**

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**Geophysical surveys in part of the
Halkyn–Minera mining district,
north-east Wales**

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SUMMARY

Induced polarisation (IP) surveys were carried out at four localities in the Halkyn - Minera area, all sited mainly on rocks of the Cefn-y-Fedw Sandstone Group north of the Llanellidan Fault. The first survey covered the Llandegla Moor area but failed to produce any evidence for a north-westward continuation of the rich Minera lode system. Regional and detailed gravity data subsequently demonstrated the existence of a pronounced Bouguer anomaly low over the western margin of the Cefn-y-Fedw Sandstone Group, including the Llandegla Moor area, suggesting that these rocks thickened rapidly eastwards, perhaps along a concealed northerly-trending fault. In an attempt to locate this fault and to test its mineral potential, trial IP surveys were carried out at three sites covering the boundary between the Cefn-y-Fedw Sandstone Group and the underlying Viséan limestones. No strong chargeability anomalies were discovered and the overlap and variability of the resistivities of the sandstones and the limestones prevented recognition of the boundary between these two rock types. The chargeability values recorded over sandstones seem to be largely dependent upon the resistivity values, suggesting that variations in the porosities of the rocks are mainly responsible.

The Bouguer low is interpreted as probably being due to the presence of high-porosity and rapidly-thickening sandstones in the Cefn-y-Fedw Sandstone Group. For these reasons the area where the low was discovered is not strongly recommended for any future exploration for extensions of the mineral veins.

INTRODUCTION

The lead-zinc bearing lodes in the Lower Carboniferous sediments of the Halkyn-Minera mining district, north-east Wales, have a long history of mining, although there are no active mines at the present time. It is unlikely that further large, near-surface deposits remain undetected in the exposed Viséan limestones but it was thought that exploration using geophysical methods might reveal mineralisation in down-dip extensions of these rocks. The induced polarisation (IP) method was therefore used for trials in areas of outcropping Cefn-y-Fedw Sandstone Group with the view to locating new deposits or extensions at depth to previously mapped deposits. The selection of the sites was based on geological evidence and also on the findings of an examination of detailed gravity data. The work was carried out intermittently over a period of several years funded in part under the Mineral Reconnaissance Programme.

GEOLOGY AND MINING

Geological information on the area is based largely on the published geological maps (Sheets 108 and 121) and the corresponding memoirs (Strahan, 1890; Wedd and King, 1924; and Wedd and others, 1927).

The survey areas lie on eastwardly dipping Carboniferous strata which rest unconformably on the Lower Palaeozoic rocks of the Clwydian Hills to the west.

The simplified geological sequence is:

Bunter Sandstone	Triassic	
-----		unconformity
Coal Measures)	
(Westphalian))	
)	
Cefn-y-Fedw Sandstone Group)	
('Millstone Grit', mainly)	
Namurian))	Carboniferous
)	
Lower Carboniferous)	
Limestone (Viséan))	
-----		unconformity
Ludlow Beds and Wenlock	Silurian	
Shale		

The two rock units relevant to this investigation are the Viséan limestones and the Cefn-y-Fedw Sandstone Group. The limestone series can be divided into the following: Basement Beds, Lower Grey and Brown Limestone, White Limestone, Upper Grey Limestone and Sandy Limestone. Above the Sandy Limestone lies the Cefn-y-Fedw Sandstone Group which consists of medium to coarse grained sandstones with interbedded shales and cherts. This group in particular shows a pronounced lateral variation in thickness, ranging from 0 to 500 m, but the underlying limestones also vary (200 m to 400 m) along strike (George, T. N., 1974).

The general north to south striking outcrop of the Carboniferous rocks is interrupted by the Llanellidan Fault, part of the Bala Fault system, which shifts the outcrop about 7 km westwards on the northern, down-throw side (Figure 1). The eastern margin of the Viséan limestones is also displaced in places by ESE-trending faults, some of which are mineralised.

The lead-zinc mineralisation occurs mainly within the Viséan limestones and, to a much lesser extent, in the overlying Namurian sandstones, where present, along about 40 km of strike extent. The ore minerals occur mainly in lodes occupying faults and in 'flats' replacing limestone. There are two sets of faults - one roughly east-west set of tension fissures perpendicular to the strike and a younger north-south set. The east-west lodes are extensively mineralised, with galena and sphalerite in a calcite gangue; the north-south cross-courses are usually barren but may carry a few specks of chalcopyrite. Local deposition of the ores was controlled to a large extent by the presence of overlying shale horizons. As no centre of concentrated mineralisation has been found, Earp (1958, p. 50) suggested that the source was a diffuse one and lay at depth below the eastern margin of the Lower Carboniferous outcrop.

SELECTION OF SITES AND GEOPHYSICAL METHODS

As is the case with most of the long established mining districts, exploration for rich, near-surface deposits has been intensive and it is unlikely that many remain undiscovered. Several recommendations for other possible exploration targets have been made; Schnellman (1959) suggested that new deposits might be found by extending the present workings to the south and into the

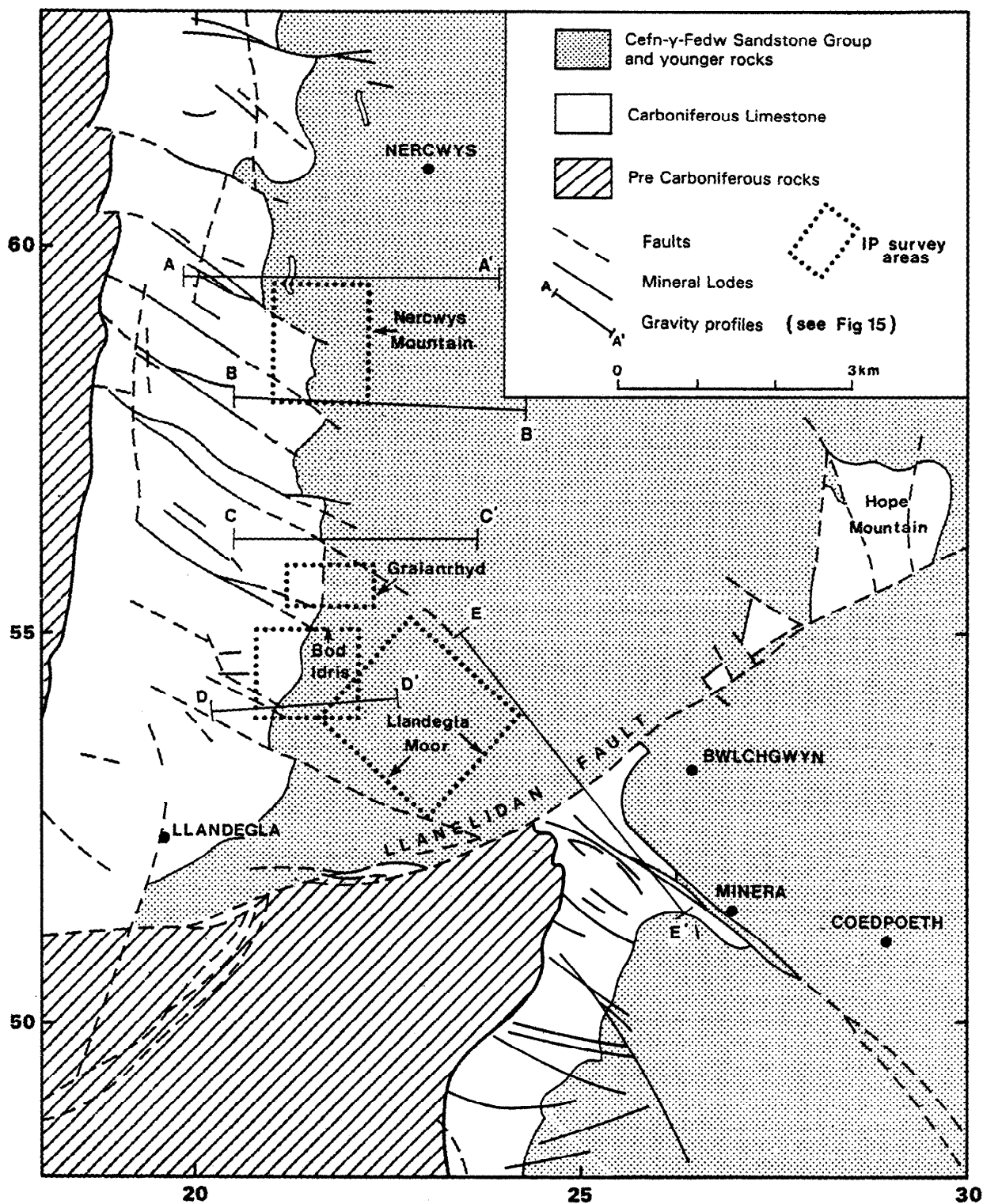


Figure 1 Simplified geological map of part of the Halkyn-Minera mining district showing locations of geophysical surveys and profiles.

cherts and grits to the east (cf. Earp, 1958, p. 44) and also in the unexplored anticline of Hope Mountain. Hughes (1959) commented that the Llandegla Moor area immediately to the north of the Llanellidan Fault might contain new deposits and that a productive vein in the limestone to the north-east should not descend deeper than 300 m. It has also been suggested (Smith, 1921) that the plugged shale in the Llanellidan Fault zone might have acted as a screen to the mineralising solutions, which accumulated in the productive Minera district, although Davies (1948, fig. 38) has noted that the fault zone itself provided fissures for upward percolating solutions which have deposited baryte and galena.

The first area investigated in the present survey, Llandegla Moor, was selected on the basis of the

occurrence of numerous lodes which disappear into the sandstones and cherts forming the triangular outcrop of Namurian sediments bounded to the south by the Llanellidan Fault (Figure 1). In particular the survey area would include any northwest extension of the rich Minera lode system. At about the same time as this survey was carried out, the BGS regional gravity survey of North Wales revealed a distinctive Bouguer anomaly gradient over the western margin of the Cefn-y-Fedw Sandstone Group. This feature was subsequently examined by a series of detailed gravity traverses, and a well-defined step-like anomaly or, in places, a Bouguer anomaly low was discovered close to the boundary between the Carboniferous Limestone Series and the overlying sandstones (Figure 15). The significance of this gravity

feature is discussed in detail elsewhere (Cornwell, in preparation) but one interpretation seems to be that this margin is a fault. In an attempt to investigate this possibility, and also to search for any possible mineralisation in this potentially promising area, a few trial geophysical profiles were obtained at Bod Idris and Nercwys Mountain.

The use of the induced polarisation (IP) method was selected as the most promising approach, mainly because it was felt that the most common conductive ore mineral (galena) might not be sufficiently concentrated to provide a good target for electromagnetic methods, and also because the resistivity data collected simultaneously could provide information on unmineralised faults and the limestone/sandstone boundary.

The MKII IP system manufactured by Hunttec Limited (Toronto, Canada) was used for the Llandegla Moor survey. A 7.5 kw generator provided power for the transmitter and the receiver recorded the primary voltage (transmitter current on) and the secondary voltage at a fixed delay time (15 ms) from the cut-off of the 1.5 s long current pulse. The apparent chargeability is defined as the ratio between these two voltages.

For the remainder of the surveys, Hunttec MkIII equipment was used with a 250W 'LOPO' transmitter. With this, the secondary voltage measurements were integrated over a time interval of 240 ms to 1140 ms after the cut-off of a 2 s current pulse. These values are, therefore, not directly comparable with those obtained using the MkII equipment. With both types of equipment, values of the primary and secondary voltages and the output current were used to calculate the apparent resistivity, chargeability and specific capacity (the ratio of chargeability to apparent resistivity). Although specific capacity has been used elsewhere to estimate ore, grade there are doubts as to the value of this parameter (Sumner, 1976, p. 206).

To give some idea of the relative depths of exploration it is useful to compare Edwards' (1977) effective depth (Z_e) parameter for the various electrode arrays used for the surveys. Z_e is defined, for a homogeneous earth, as the median depth at which one half of the total signal originates from above and one half from below.

Dipole-dipole array (50 m dipoles):

Dipole centre separations (m)	Z_e (m)
100 (n=2)	21
150 (n=3)	35
200 (n=4)	48
250 (n=5)	61

Wenner array:

Electrode separations (m)	Z_e (m)
25	13
50	26

Pole-dipole array (Llandegla Moor Survey)

$$P_1 P_2 = P_2 C_1 = 60 \text{ m} \quad Z_e = 31 \text{ m}$$

Trial surveys using electromagnetic (Slingram) methods have been made at several localities in the Halkyn-Minera mining district (Cornwell, 1979). These were largely unsuccessful in producing clear indications of mineralisation but in several cases man-made sources of electrical interference proved to be a difficulty.

INDUCED POLARISATION SURVEYS

Llandegla Moor

The Llandegla Moor area extends across the open moorland between Rhydtalog [234550] and Llandegla [196524] and is crossed by the A5104 road. The ground lies at about 350 m above OD and Moel Garegog reaches an elevation of 413 m just outside the area surveyed.

The area lies on the widest part of the outcrop of the Cefn-y-Fedw Sandstone Group where it is terminated on the south side by the Llanellidan Fault (Figure 1). The thickness of the group is, at the most, 207 m on Ruabon Mountain but near Llandegla may increase to 520 m (Wedd and others, 1927), the change possibly occurring mainly across the Llanellidan Fault. The Lower Carboniferous sediments show a similar change across this structure (George, 1974). The presence of extensive drift has hindered detailed geological mapping (and probably discouraged mineral exploration) in the area covered by the geophysical survey. The dominant lithology is pale massive sandstone but a chert horizon striking north-eastwards has been traced (Figure 2) to the Bod Idris Fault; shale is subordinate. Within the survey area there are a small disused mine and some levels which are not specifically listed in the Mineral Resources Memoir (Smith, 1921); the mine debris provides no indication of sulphide mineralisation.

The survey lines were laid out by compass 150 m apart in a north-east to south-west direction perpendicular to the anticipated strike direction of the mineral lodes. Most of the lines were roughly parallel with - and to the south of - the main (A 5104) road but three traverses had to be terminated at the road as the power cable could not safely be continued across it. Observations were made at 60 m intervals using a pole-dipole configuration with $P_1 P_2 = P_2 C_1 = 60 \text{ m}$. The results are shown as maps of apparent resistivity (Figure 3), chargeability (Figure 4) and specific capacity (Figure 5).

Apparent resistivity values in the survey area vary generally between 100 and 600 ohm m, with a few values reaching up to 1200 ohm m, but the contour pattern does not reveal any immediately recognisable structure. There is a tendency for the larger values to occur over the higher ground in the centre of the area and the lowest values over the low-lying and sometimes marshy ground to the south-east. This correlation is probably due to the presence of a less conductive, gently dipping horizon on the hill tops, but the variation in the water table height might be a contributory factor. The north-easterly strike direction of the sediments is only vaguely indicated in places (the southern part of the area, for example) by the anomaly pattern.

In Figure 4 the apparent chargeability data have been contoured at 0.25 ms intervals. Comparing this map with that of the apparent resistivity (Figure 3), there is no immediately obvious correlation of the anomalies but there is a very broad relationship between the two properties in that chargeability values tend to increase with the resistivity values (Figure 6). On the maps this is perhaps seen most clearly by comparing the south-eastern part, where the low resistivity area also yielded low chargeability values, with other areas where higher resistivity and higher chargeability values were recorded.

In the south-east the chargeability values are 0.75 ms or less but over the remainder of the area the background value appears to be between 0.9 ms and 1.0 ms with values reaching 2.0 ms or 2.25 ms in anomalous areas. The largest of these chargeability anomalies curves round from the centre of line 0E to the north-eastern end of line 300E. A less intense anomaly strikes towards the south-east across an old adit at B (Figure 4) and there are also small areas with values greater than 1.6 ms north-west of, and on, lines 900E (near the mine shaft at C), 550W and 300W.

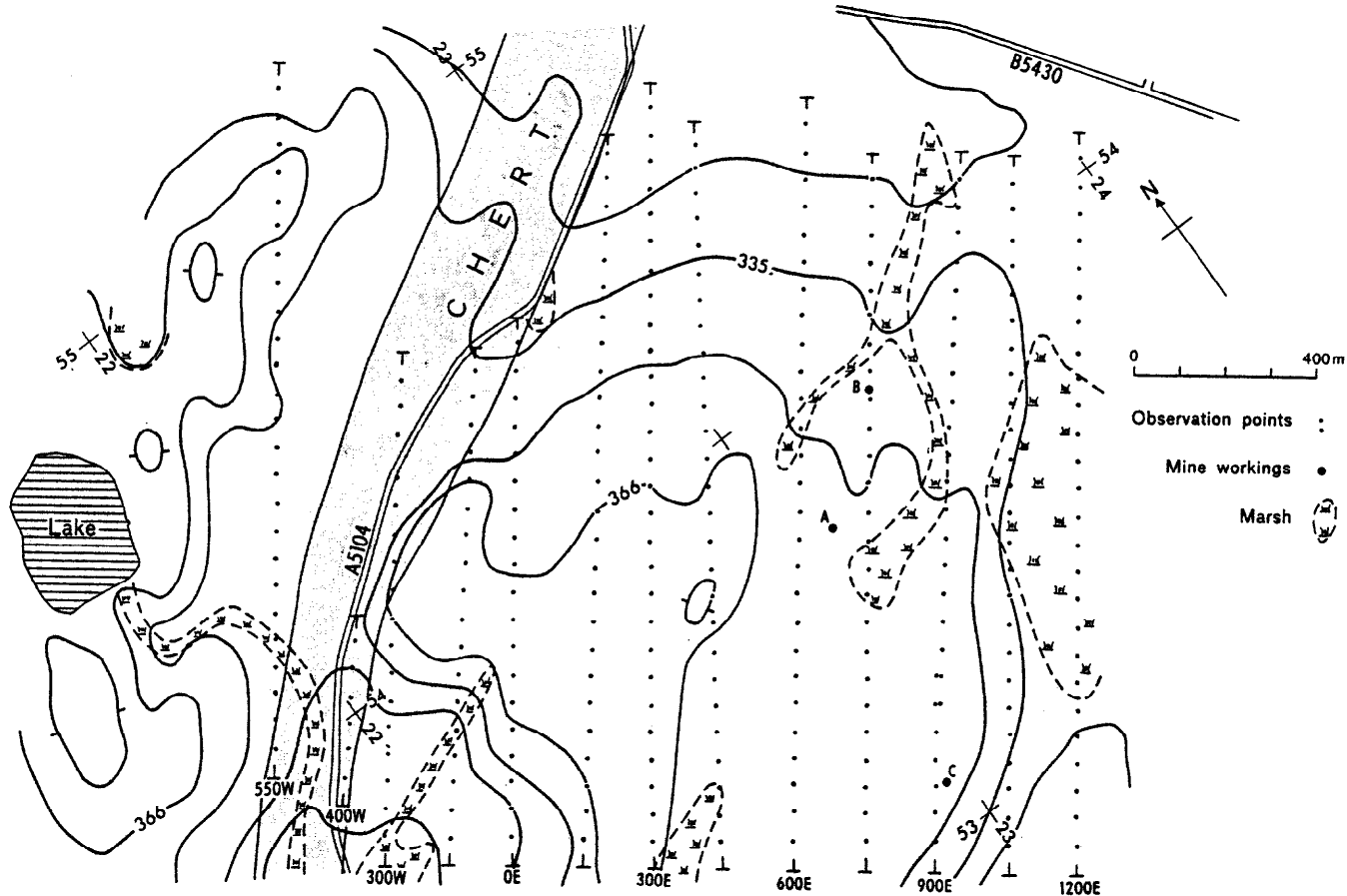


Figure 2 Topographical and geological map of the Llandegla Moor area and locations of geological observation points.

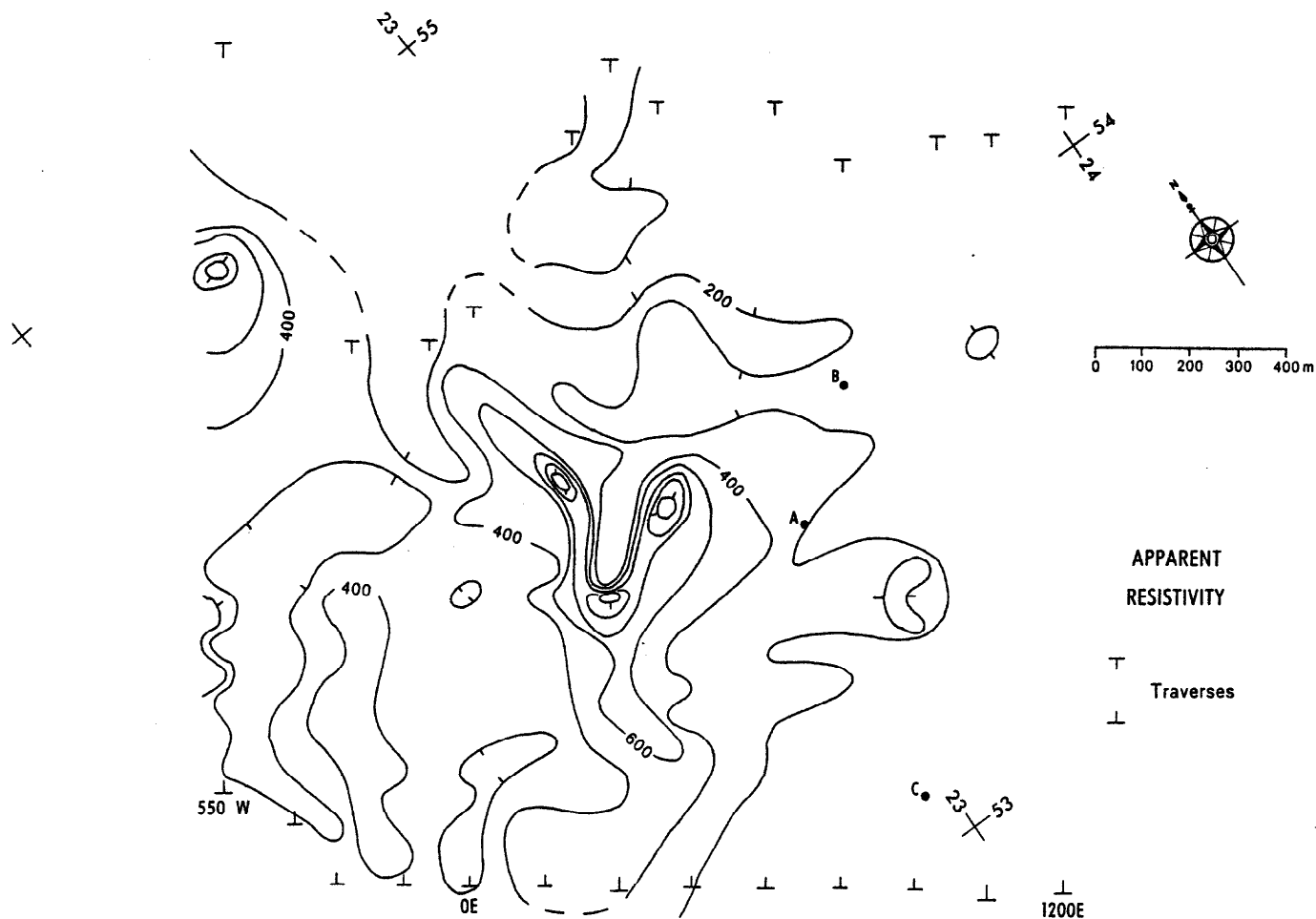


Figure 3 Apparent resistivity map of the Llandegla Moor area with contours at 200 ohm metre intervals.

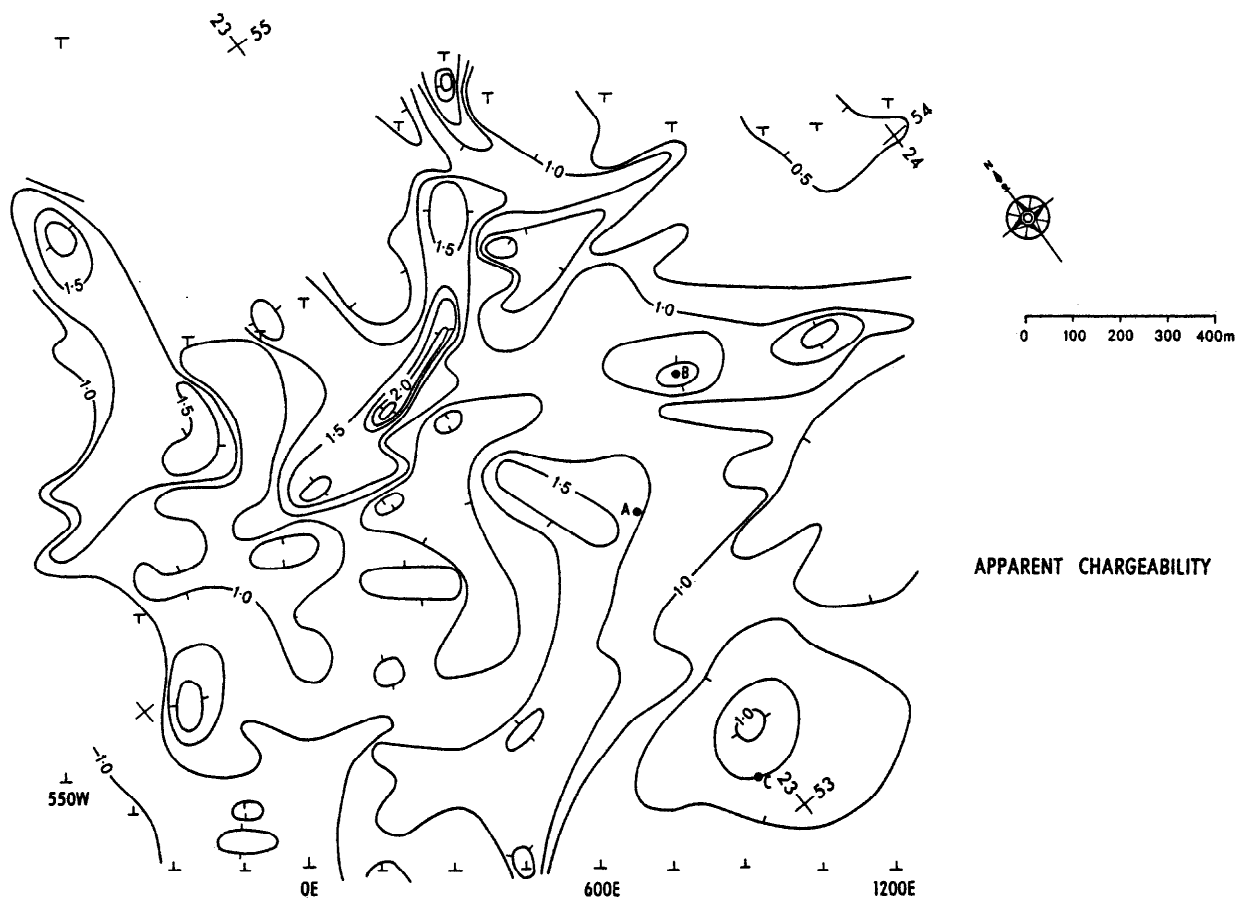


Figure 4 Apparent chargeability map of the Llandegla Moor area with contours at 0.25 ms intervals.



Figure 5 Specific capacity map of the Llandegla Moor area and positions of underground water pipes. Contour interval $0.25 \mu\text{F/m}$.

The survey area is however underlain by a system of pipes carrying water between reservoirs and it is probable that these are responsible for some of the anomalies. The locations of the pipes according to the original site maps are shown in Figure 5 and it is obvious that one pipe crossing the area from the north-west to the south-east coincides approximately with the well-defined specific capacity anomaly. This pipe is made of cast iron, has a diameter of 0.15 m and lies at a depth of between 0.3 and 0.9 m while the pipe crossing the north-west corner, where there is no obvious anomaly, is made of concrete. Two other isolated high readings were obtained on lines 150W and 300W but these coincide with the main road. The only significant anomaly remaining is the narrow feature reaching a maximum value of 1.5 ms on line 300E (Figure 5) but the feature has only limited extent.

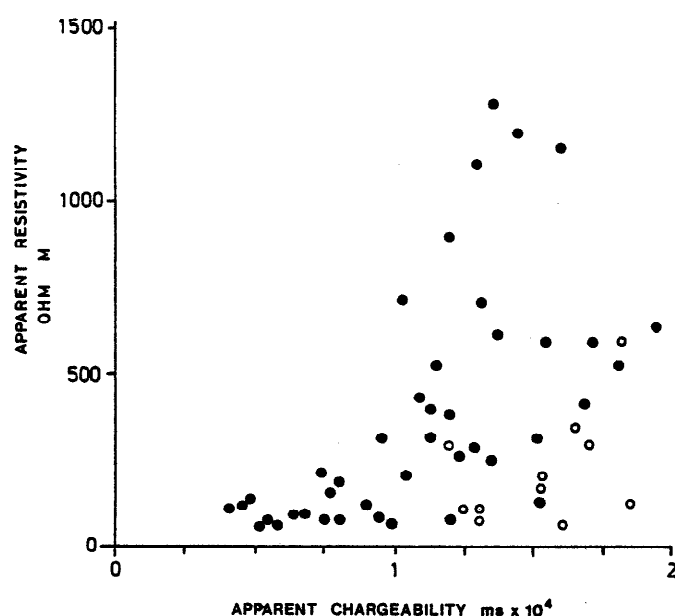


Figure 6 Apparent resistivity versus apparent chargeability for a selection of stations in the Llandegla Moor area. Values recorded over pipes are shown as open circles.

Although it appears that the pipes are likely to be responsible for the more pronounced specific capacity anomalies (Figure 5 and shown in a different manner in Figure 6 by the relevant values plotting as low resistivity/high chargeability points) it is unfortunate that the pipe in the south-eastern part of the area also coincides with the mine at B (Figure 5) and also with the general strike of the lodes in the adjacent areas. Anomalies away from the area underlain by pipes (Figure 5) are not sufficiently large or well-defined to suggest economic mineralisation.

Nercwys Mountain

At this (Figure 7) and at the two following locations trial IP and resistivity surveys were carried out primarily to investigate the possible existence of a fault suggested by the Bouguer gravity anomaly data.

During initial surveying at these locations, a dipole-dipole array was used with 50 m dipoles and dipole-centre separations of 100 m ($n=2$) to 250 m ($n=5$). Electrical interference due to man-made sources was encountered which made it difficult to obtain reliable measurements (particularly of chargeability) and the array was eventually abandoned in favour of constant separation traverses (CSTs) using the Wenner array, which has a superior signal-to-noise ratio. To investigate vertical resistivity variations, a number of electric soundings were carried out using an expanding Wenner array with electrode separations of 1 m to 70 m; the full results of these soundings have been presented by

Kimbell (1978) and are discussed only briefly in this report.

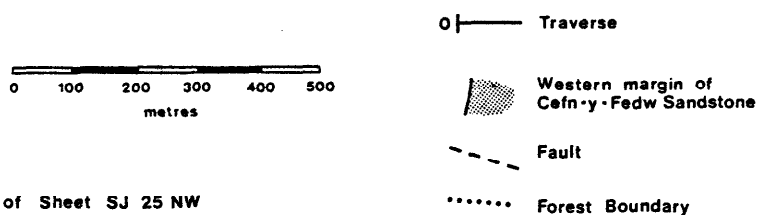
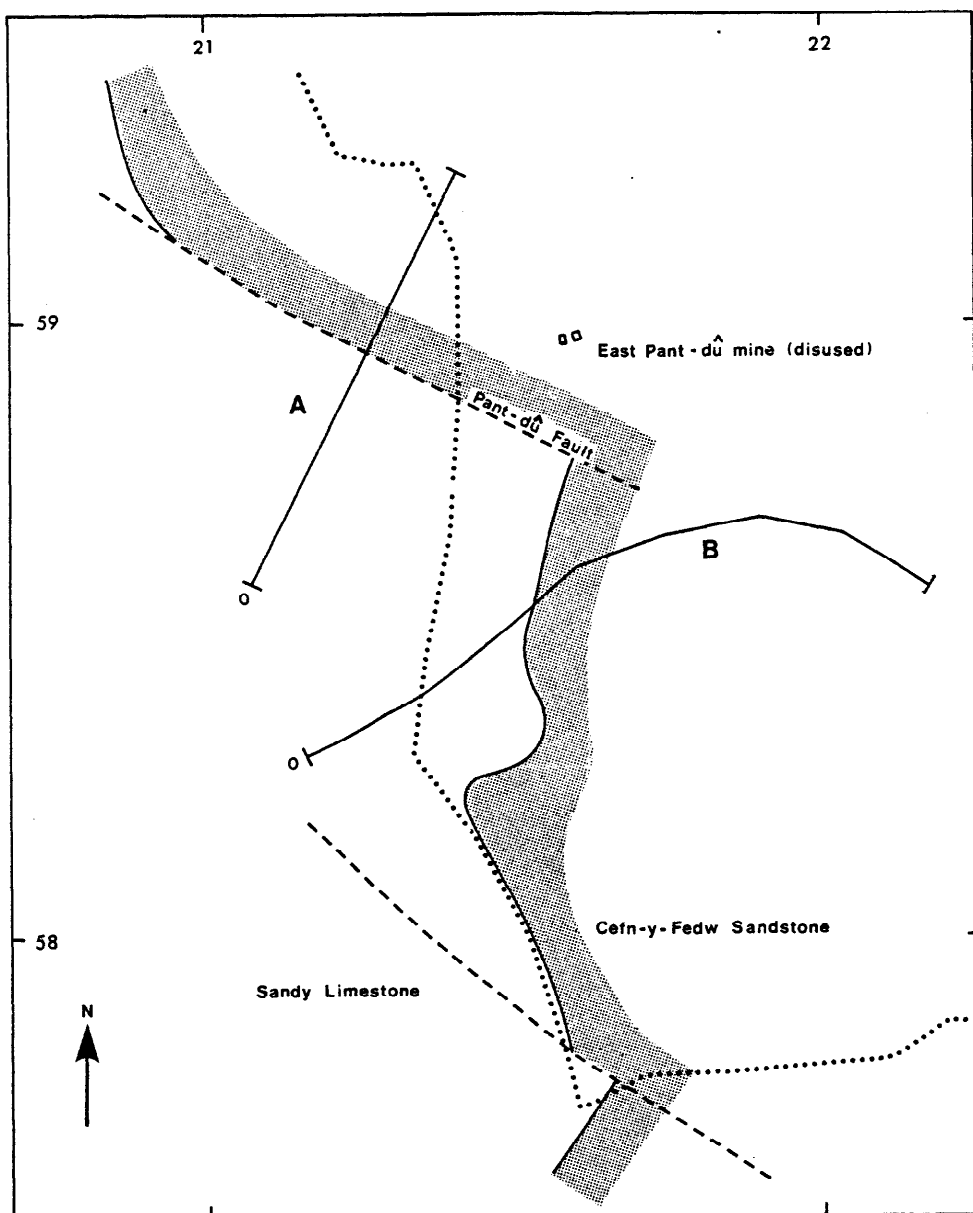
Line A (Figure 7) crosses the mineralised Pant-dû Fault at about 400NE. Using evidence from the Engine Shaft at East Pant-dû Mine, Strahan (1890) estimated the downthrow to the north of the fault to be of the order of 100 m. It is thus likely that, beneath line A, 50 m or more of sandstone overlies the limestone to the north of the fault; on the basis of the effective depth parameter (Z_e), it is possible that the underlying limestone may influence measurements at the wider dipole separations.

The $n=2$ data (Figure 8) show high resistivity shallow sandstone immediately to the north of the fault; lower resistivities are indicated at greater depth here and these may be due to the underlying relatively conductive limestone and/or sandstone beneath the water table although water filled fractures or possibly conductive mineralisation in the vicinity of the fault may contribute. At the north end of the line the situation is reversed with the lower apparent resistivities being measured at the smaller dipole separations. The lowest apparent resistivities indicated for the sandstone are very similar to those measured over the limestone and it appears, on this evidence, that the resistivity method will not allow unambiguous discrimination between these formations.

Too few reliable readings were obtained to justify the plotting of a chargeability pseudosection for this line although some high, but erratic, values were obtained at the wider dipole separations in the vicinity of the Pant-dû Fault.

Line B crosses the limestone/sandstone boundary at about 450E; however, the solid geology in this area is obscured by a layer of collapsed sandstone debris presumed to result from the solution of the upper limestones (Strahan, 1890). A gentle eastward dip of about 8° is inferred from the displacement of the beds by the Pant-dû Fault, an extension of which is likely to cross the survey line obliquely at about 750E. Calculations assume a colinear array and errors in apparent resistivity values therefore result from the distortion of the array geometry around bends in this line, which was laid along a path running through the dense forest. It is estimated that the errors involved are less than 5% with the Wenner array and less than 10% with the dipole-dipole array.

The apparent resistivity pseudosection (Figure 9) shows greater variability over the sandstone than the limestone. This may be because of lithological changes, for example shale or chert layers, or variations in the degree of cementation of the sandstones, although factors such as water table depth and overburden resistivity could be significant. Both the pseudosection and the CST profile show a zone of high apparent resistivity centred at 425E which is likely to be due to a more resistive limestone horizon (there is an old limestone quarry just to the north of the line here). The resistive zone extends some 100 m east of the mapped limestone margin; this may indicate an error in the mapping or it is possible that the shallow dips keep the limestone close to the surface beneath thin sandstone cover. If the latter is the case the relatively sharp apparent resistivity decrease at around 500E - 550E might relate to a steepening of dip or downfaulting of the resistive bed. However, vertical electric soundings in this vicinity suggest that it is not necessary to invoke such structures since the resistivity decrease apparently relates to an increase in thickness and decrease in depth of a conductive zone above the limestone at the base of the Cefn-y-Fedw sandstone; the conductor is probably a porous sandstone beneath the water table (Kimbell, 1978). It should be noted that water content is not the only factor controlling the resistivity of the Cefn-y-Fedw Sandstone Group since other electric soundings in the Nercwys Mountain area have detected resistive layers (greater than 1000 ohm m) within this group which apparently lie beneath the water table. The high



Part of Sheet SJ 25 NW

Figure 7 Geophysical traverses in the Nercwys Mountain area.

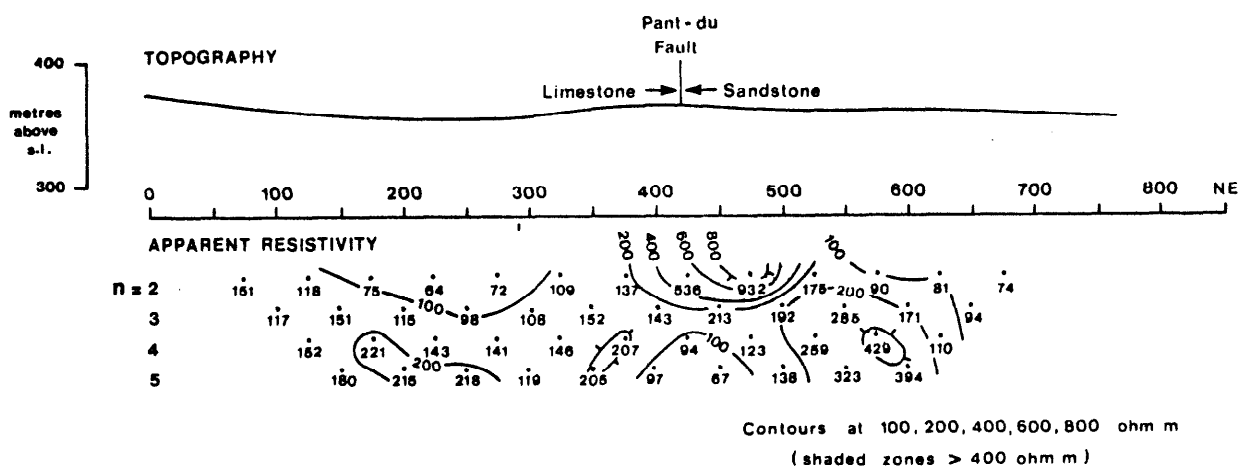


Figure 8 Apparent resistivity pseudosection for line A, Nercwys Mountains.

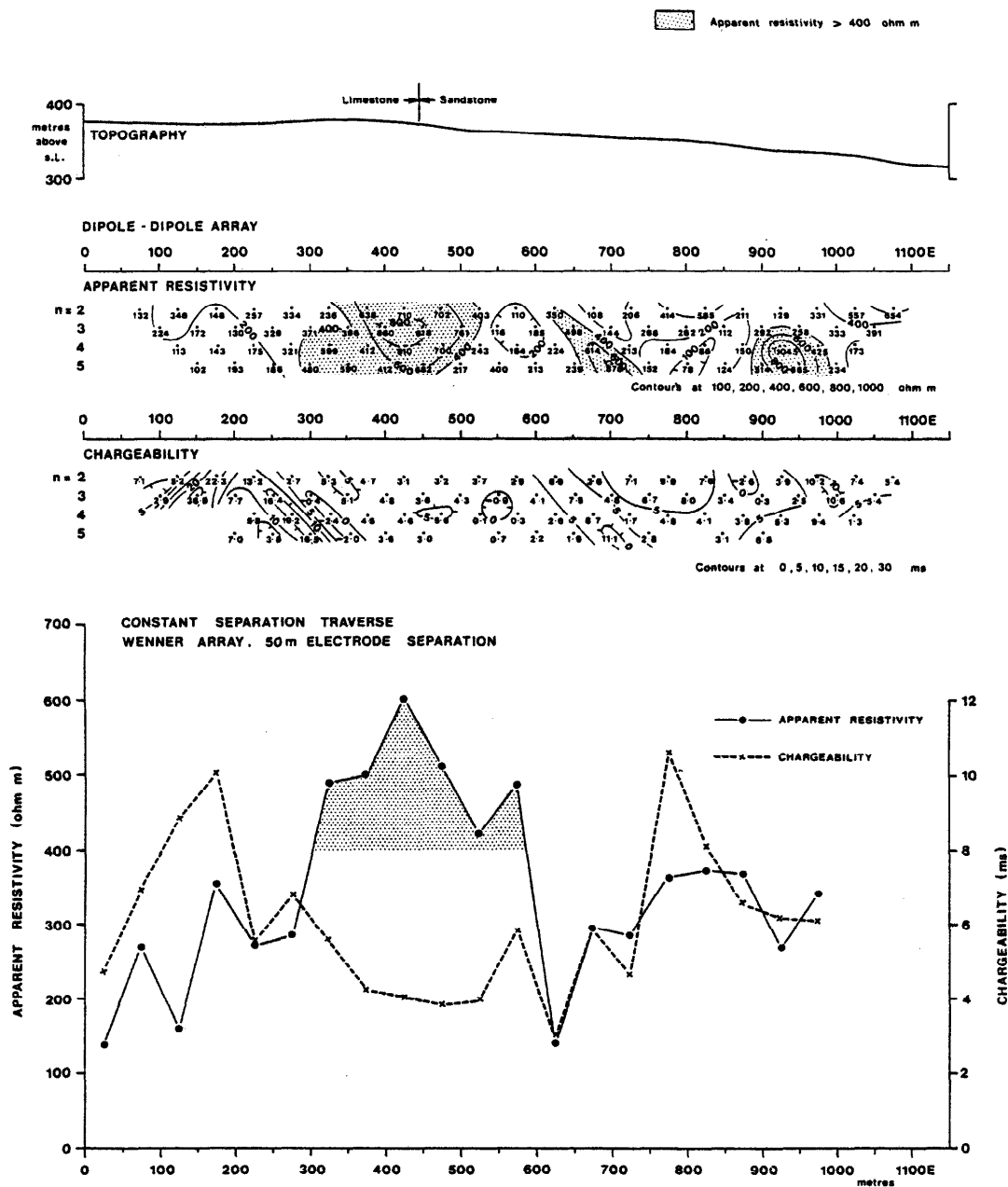


Figure 9 Pseudosections and CST profiles for line B, Nercwys Mountain.

resistivity zone centred at 925E at the $n=4$ level in the pseudosection (Figure 9) probably relates to such a layer. The resistivity soundings indicate a considerable overlap in the ranges of resistivity associated with Lower Carboniferous Limestone and Cefn-y-Fedw Sandstone Group (Kimbell, 1978).

An IP anomaly centred at 200E (Figure 9) is due to a grounded metal fence bordering the forest. Away from the influence of the fence, chargeabilities over the limestone are consistently low (mostly less than 6 ms); over the sandstone, chargeabilities are more variable, though generally low and occasionally negative. There is a chargeability peak at about 775E on the CST which the dipole-dipole traverse indicates is due to a source at shallow depth: this may be caused by minor mineralisation associated with the Pant-dû Fault although it could simply result from a concentration of clay minerals. Other minor chargeability highs appear on the pseudosection at 700E ($n=5$) and 1000E but these are unlikely to indicate significant mineralisation.

Graianrhyd

A CST and several electrical soundings were carried out in the vicinity of the limestone/sandstone contact at [217 555] about 700 m south of Graianrhyd (Figure 1), where it has been mapped as a faulted contact. Some of the traverse data were strongly influenced by the high voltage power lines which pass through the area. The available results suggest that the apparent resistivity is more dependant upon the topography than the geology.

This may be because more electrically resistive strata outcrop at the hill tops but the sounding data indicate that variation in water table depth is likely to be an important factor. As at Nercwys Mountain, chargeabilities are slightly higher and more erratic over the sandstone than over the limestone.

Bod Idris

This is the most southerly of the three survey areas covering the boundary of the Cefn-y-Fedw Sandstone Group; it lies adjacent to the Llandegla Moor survey area (Figure 2). Bouguer gravity anomaly data here indicate a particularly well-marked step-like feature to the east of the geological boundary (DD', Figure 15).

Line 0N (Figure 10) was covered with the dipole-dipole array and with CSTs using electrode separations of 50 m and 25 m (Figure 11). The effective exploration depths quoted earlier indicate that the 25 m CST investigates at shallower depth than the $n=2$ dipole-dipole array while the 50 m CST investigates between the $n=2$ and $n=3$ levels. When compared on the basis of these effective depths the resistivity and chargeability data from all the arrays fit together reasonably well. Over the limestone the data indicate a general westward and downward increase in resistivity which may relate to a decrease in mean porosity associated with the transition from sandy limestone to the purer, lower members of the limestone sequence. At the eastern margin of the limestone all the arrays show a distinct increase in resistivity on moving onto the Cefn-y-Fedw Sandstone Group (which coincides with moving above the level of the springs on the hill-side). The apparent resistivities, which are more variable

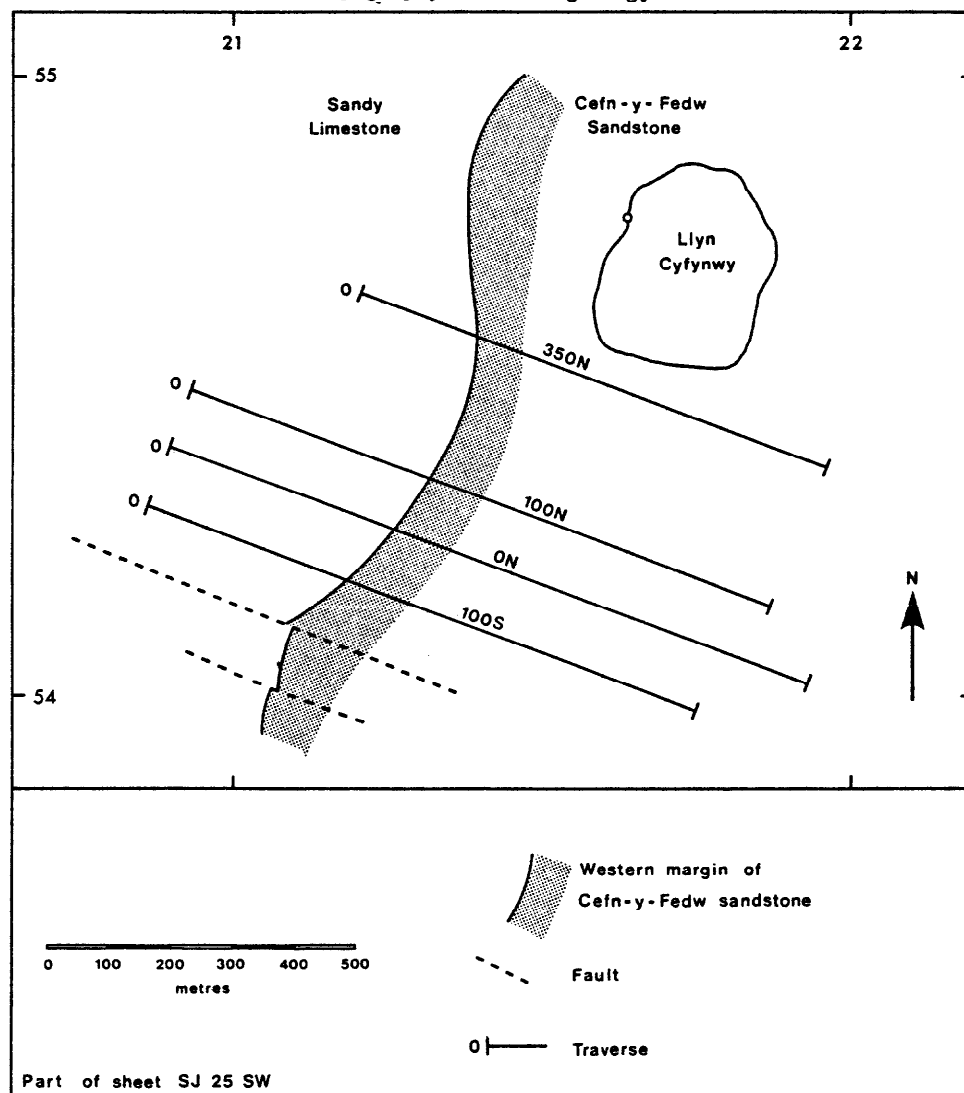


Figure 10 Geophysical traverses in the Bod Idris area.

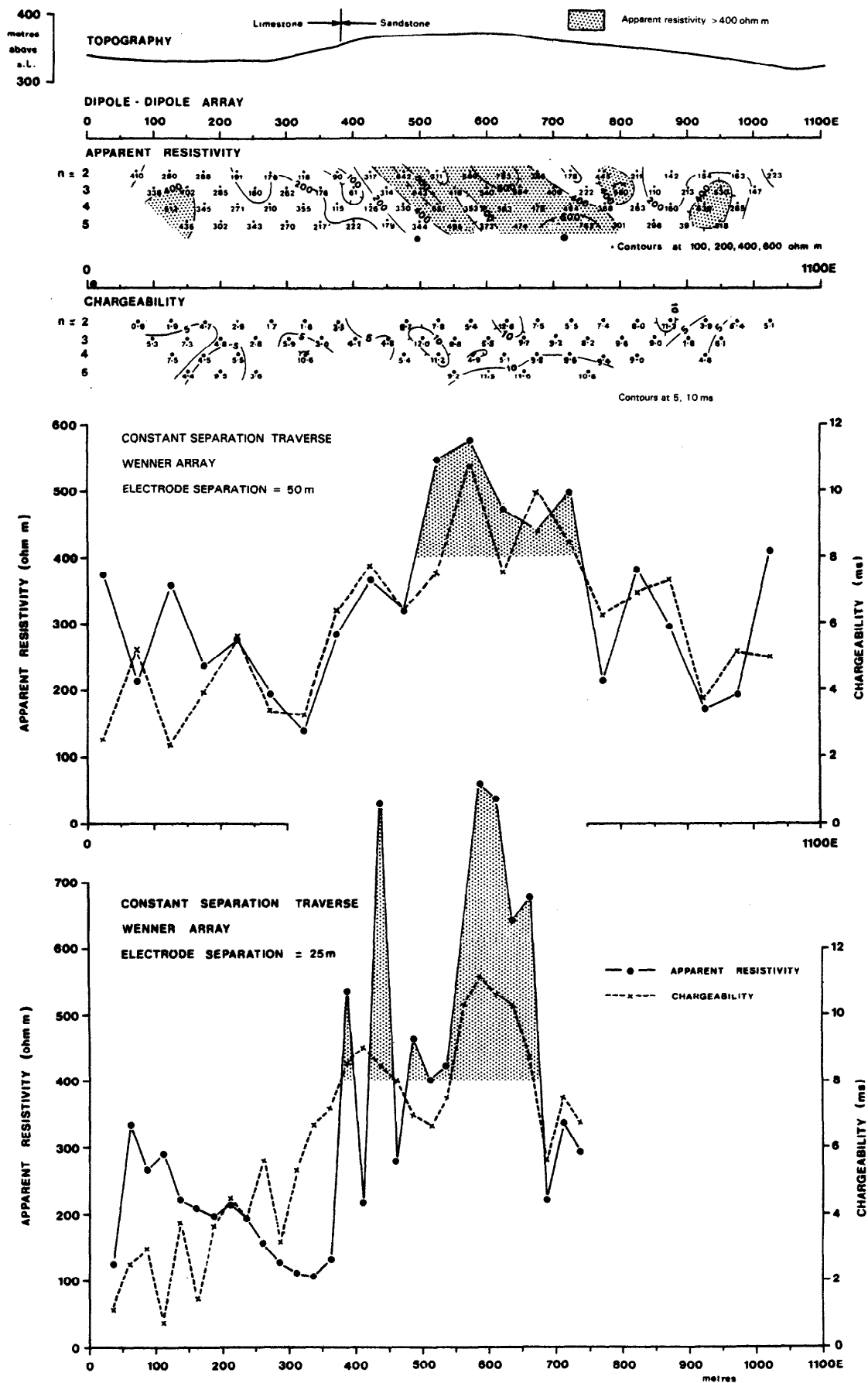


Figure 11 Apparent resistivity and chargeability results for line 0N, Bod Idris.

on the sandstone than the limestone, reach a maximum at the top of the hill and generally decrease as the arrays are moved on to the lower ground to the east. Topography alone has an influence on apparent resistivity, particularly for the dipole-dipole array, with artificially high apparent resistivities being measured over hill tops. However, in this case it is considered that a more important factor is the greater thickness of dry, electrically resistive sandstone above the water table at higher topographic elevations. The presence of this layer is demonstrated by the higher peak apparent resistivities measured with the 25 m CST than with the other arrays. The dipole-dipole resistivity pseudosection shows an apparent eastward dip, which is in agreement with the observed geology, but it should be noted that much of the apparent structure (particularly around 500E (Figure 11)) can be attributed to the effect of local near-surface resistivity variations beneath the transmitting dipole. As at Nercwys Mountain, there is evidence of high resistivity zones within the Cefn-y-Fedw Sandstone Group but beneath the water table, in this case at about 750E and 950E.

In common with the other survey areas, chargeabilities are generally somewhat higher over the sandstone than over the limestone. It is unlikely that any of the minor chargeability highs observed on this line (or the other lines in this area) are associated with economic mineralisation. It would, however, be of interest to use a higher power transmitter to explore at greater depth the zone around the geological boundary where the present dipole-dipole survey could only effectively explore down to $n=3$ (with a single higher, but somewhat suspect, measurement at the $n=4$ level).

Additional 50 m CSTs were carried out at 100S, 100N and 350N and the contoured data are shown in Figures 12 to 14. The resistivity profiles are similar to that for line 0N and amenable to the same interpretation. At the western end of line 350N there is a high resistivity zone apparently lying just within the limestone, although it is

possible that the mapping of the limestone/sandstone boundary is inaccurate here. The generally lower resistivities found towards the west are likely to relate to water seepage southwards from Llyn Cyfynwy. On the southern three traverses, bands of higher chargeability lying approximately parallel to the strike direction at 575E and 675E (Figure 13) may be due to changes in the porosity of the Cefn-y-Fedw sandstone: these show a positive correlation with apparent resistivity and do not appear on the specific capacitance map (Figure 14).

Summary of electrical properties

To summarise the observed electrical properties, the statistics of a sample of the data collected in this survey have been calculated (Table 1). The data from the 50 m CST's in the Nercwys Mountain, Graianrhyd (at localities remote from the power lines) and Bod Idris areas have been divided into two sets using the boundary between the Carboniferous Limestone and Cefn-y-Fedw Sandstone Group shown on the geological maps. Greater weight is given to results from the Bod Idris area, since more data were collected there, but the statistics do underlie trends apparent in all three areas (and in the dipole-dipole data).

The contrast in mean apparent resistivity between the two formations is relatively small, while the standard deviation about the mean is greater for the sandstone than the limestone. The chargeability values on the sandstone have a higher mean and standard deviation than those on the limestone. A distinct positive correlation exists between resistivity and chargeability with the sandstone (cf. Figure 6) but not with the limestone; there is thus some justification for using the specific capacity parameter with the former but not with the latter.

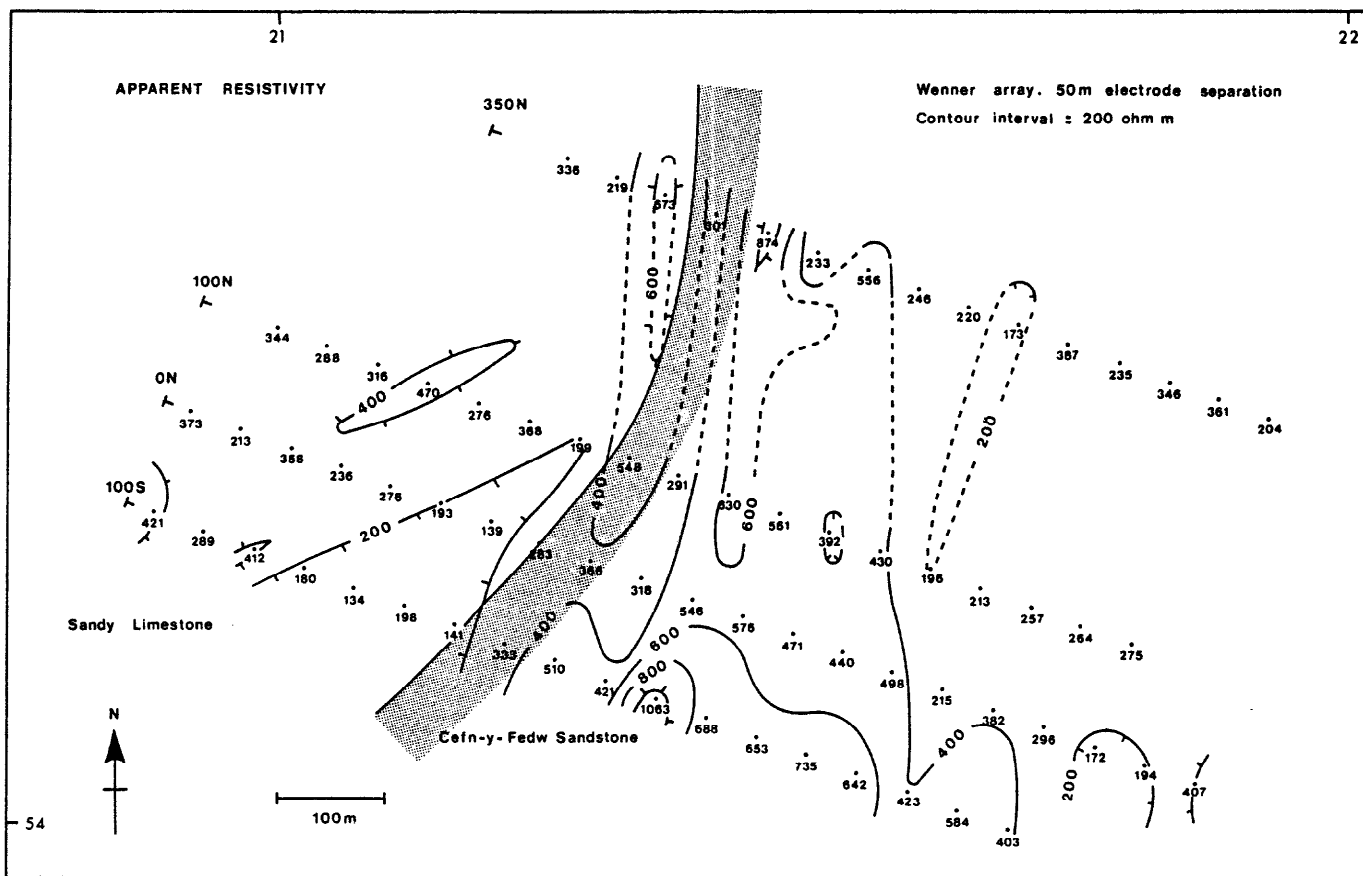


Figure 12 Apparent resistivity map of the Bod Idris area.

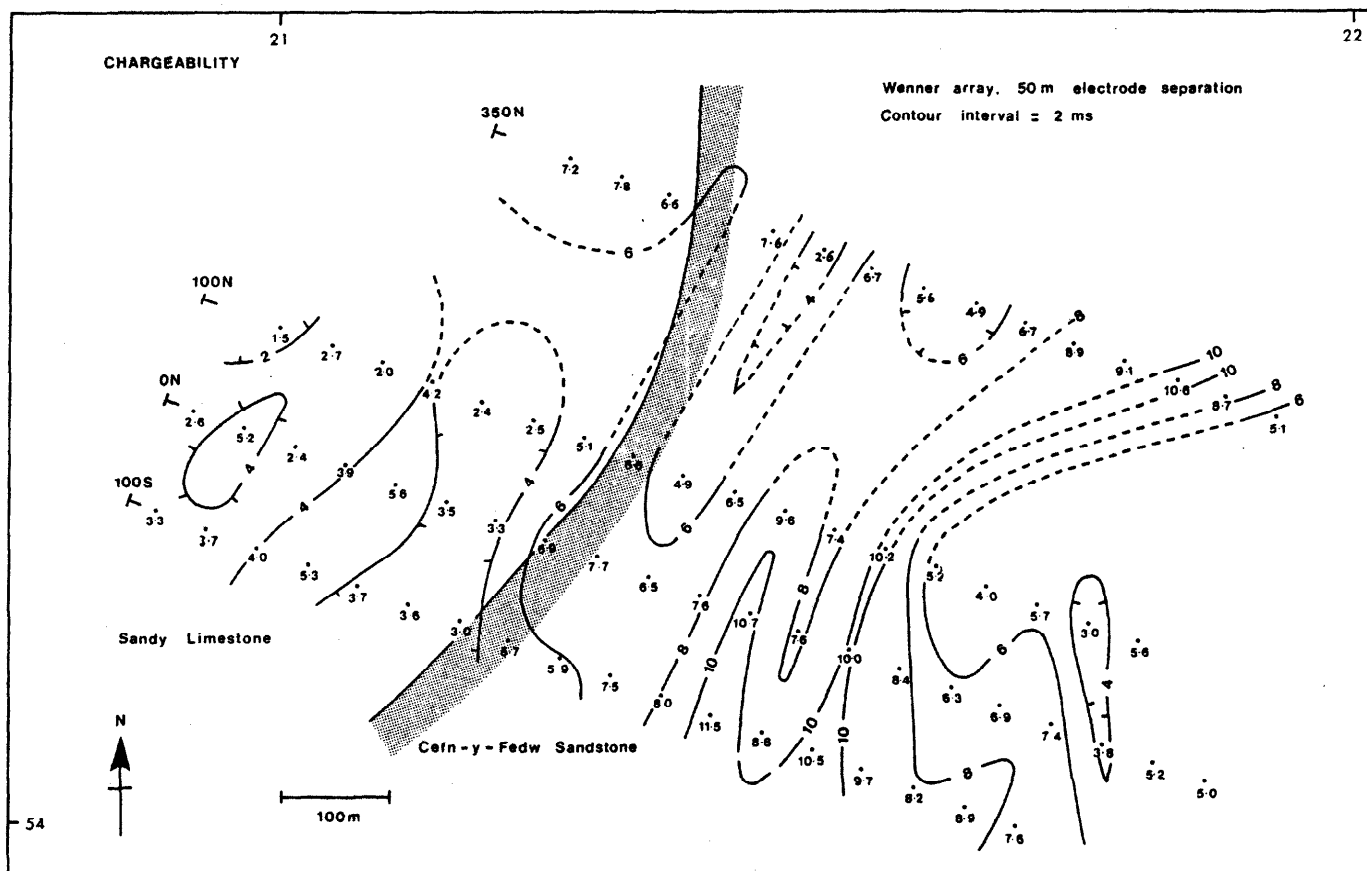


Figure 13 Chargeability map of the Bod Idris area.

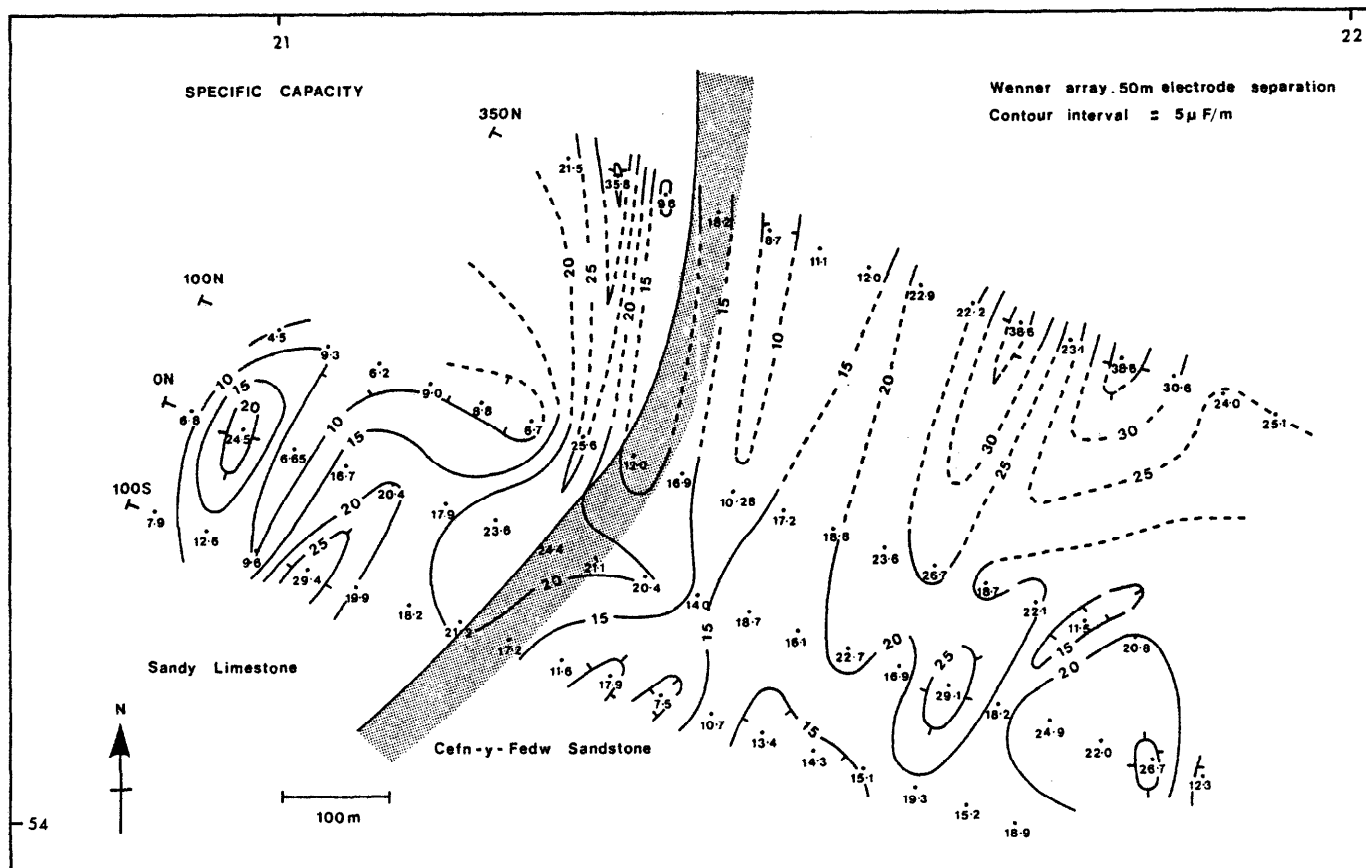


Figure 14 Specific capacity map of the Bod Idris area.

Table 1 Statistics of data from constant separation traverses
(50m electrode separation)

	Lower Carboniferous Limestone		Cefn-y-Fedw Sandstone Group	
	Resistivity (ohm m)	Chargeability (ms)	Resistivity (ohm m)	Chargeability (ms)
Number of data points	39	39	64	64
Mean	313	4.48	381	6.72
Standard deviation	123.5	1.94	185.5	2.17
Correlation coefficient	-0.056		0.56	

The tendency for chargeability values to increase with the apparent resistivity is well known in IP studies and the use of the 'specific capacity' in the time domain method and the 'metal factor' in the variable frequency method are designed to compensate for this. The usual explanation of this phenomenon is that, for a given metal content, as the porosity increases (and the resistivity decreases in a saturated rock) a smaller proportion of the total current paths are blocked by the metal grains causing the IP effect.

There is little evidence that, in the survey areas visited, there are sufficient dispersed metallic minerals to cause an IP effect, and the presence of a small content of clay minerals in the sandstones is a more likely explanation for the chargeabilities observed.

The magnitude of the IP effect is dependent in a complex way upon the clay-mineral content of the rock (Worthington and Collar, 1984) as well as upon the salinity of the pore fluid, and the saturation level and the porosity of the rock. It is unlikely that variations in the chargeability of the Cefn-y-Fedw sandstones are simply due to changes in clay content, since this would result in an inverse correlation between resistivity and chargeability. The results suggest that variations in porosity and saturation level are the main factors controlling resistivities and these may therefore influence the (clay-related) chargeabilities in an analogous fashion to the phenomenon described above for metallic mineralisation.

DISCUSSION

The IP surveys were unsuccessful in detecting good indications of mineralisation. It is, however, possible that the nature of the mineralisation makes it difficult to detect using this method, perhaps because any galena present occurs only in very narrow veins. The surveys indicate that there is not a consistent resistivity contrast between the limestone and the sandstone and the usefulness of such surveys in elucidating structure is likely to be limited. The resistivity of the Cefn-y-Fedw Sandstone Group is the more variable, apparently because of changes in water table depth as well as changes in lithology and porosity. The limestone resistivity is generally lower than the values of 1000 ohm m or more expected for this rock type, probably because of the presence of sandstone horizons in the 'Sandy Limestone' just below the Cefn-y-Fedw

Sandstone Group. It is also noted that a progressive decrease in resistivity was observed passing eastwards and down-dip on the Viséan limestones on Halkyn Mountain, just to the north of the area shown in Figure 1 (Cornwell, 1979).

On a more regional basis it is of interest to review the essentially negative findings of these IP surveys in the light of a recent interpretation of the gravity data (Cornwell, in preparation; traverse data shown in Figure 15). Several interpretations of the Bouguer anomaly low were considered, in addition to the fault model investigated in this report, and the most likely explanation seems to be the presence of low density, high porosity sandstones in the Cefn-y-Fedw Group with the boundary between these sediments and the underlying Viséan limestones locally steepened in a syncline, possibly fault bounded. As the sandstones of the Cefn-y-Fedw Sandstone Group are not generally favoured host rocks for mineralisation, the presence of a Bouguer anomaly low is regarded as being discouraging from the exploration point of view. This is partly because the local presence of steep dips would rapidly remove the Viséan limestones out of surface exploration range and, additionally, the presence of high porosity sandstone is itself considered a disadvantage. If the sandstones were poorly cemented at the time of mineralisation then they could have allowed wide dispersion of the ore-bearing fluids; alternatively if the rocks were cemented at that time then subsequent chemical action which has removed the calcite cement (D. J. Lowe, personal communication) would probably also destroy the calcite gangue of any mineral veins. It is perhaps significant to note that where a distinct Bouguer anomaly low is not associated with the Cefn-y-Fedw Sandstone Group (i.e. south of the Llanellidan Fault in Figure 1 and north of the area shown in Figure 16) mineral veins extend from the limestone boundary several kilometres laterally into the sandstone (e.g. at [2649] in Figure 1). On Esclusham Mountain, south of the Llanellidan Fault the sandstones are well cemented, (D. J. Lowe, personal communication) and the dips are low; in the Halkyn area, north of Figure 16, the sandstones of the Cefn-y-Fedw Group are replaced at the top of the limestone by thick cherts.

The mining evidence (Smith, 1921; Earp, 1958) indicates that exploration for eastern extensions of the known lodes between the Llanellidan Fault and the Nant Figillt Fault (Figure 16) has been generally unsuccessful. The Glyndwr Mine [220611], for example, failed to locate

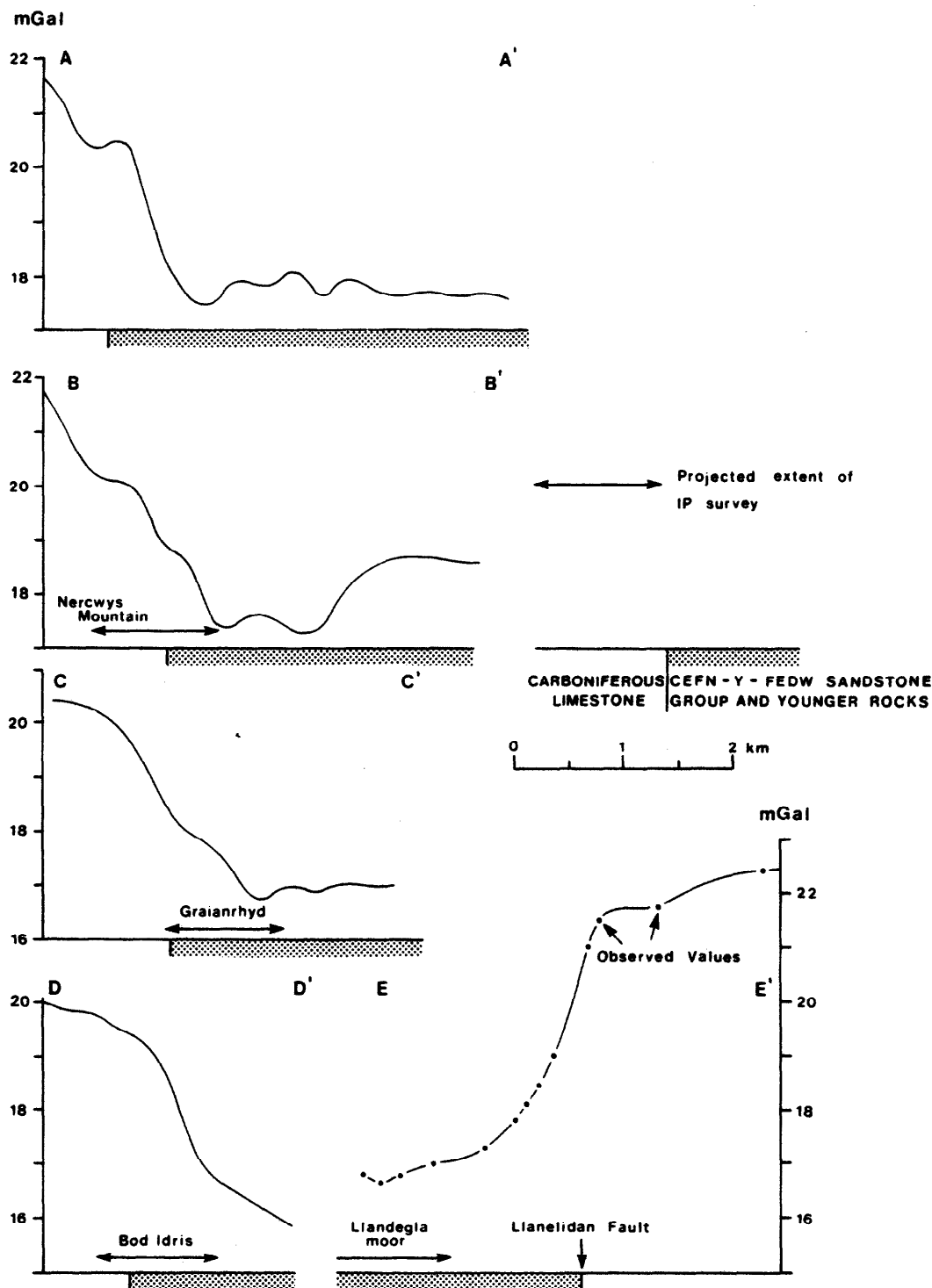


Figure 15 Bouguer gravity anomaly profiles for traverses AA' to EE' (locations shown in Figure 1).

any extension to the Coed Cynric Vein but did prove a syncline in the Cefn-y-Fedw Sandstone Group which also coincides with a local Bouguer anomaly low (Figure 16). Some mineralisation was discovered in the area in the form of 'flats' in the Top Flat Limestone near the top of the limestone sequence.

The boundary between the Carboniferous Limestone and the Cefn-y-Fedw Sandstone Group is, however, as difficult to define in this area as it is further south, because of the alternation of sandstone and limestone beds at the top of the Carboniferous Limestone Series and the presence of thin limestones, such as the Little

Flat Limestone in the Fron Haul Mine [222621], within the sandstone group.

In the same area as the Fron Haul Mine the Bouguer anomaly map shows (Figure 16) a low narrowing northwards as the Cefn-y-Fedw Sandstone Group thins out. The high to the east [225600 and northwards] coincides with the upper part of the Cefn-y-Fedw Group and the lower Coal Measures, indicating the restricted nature of the source of the gravity low in this area. The high is thought to represent a return to the normal 'background' Bouguer anomaly level, possibly enhanced by the presence of undiscovered limestone beds.

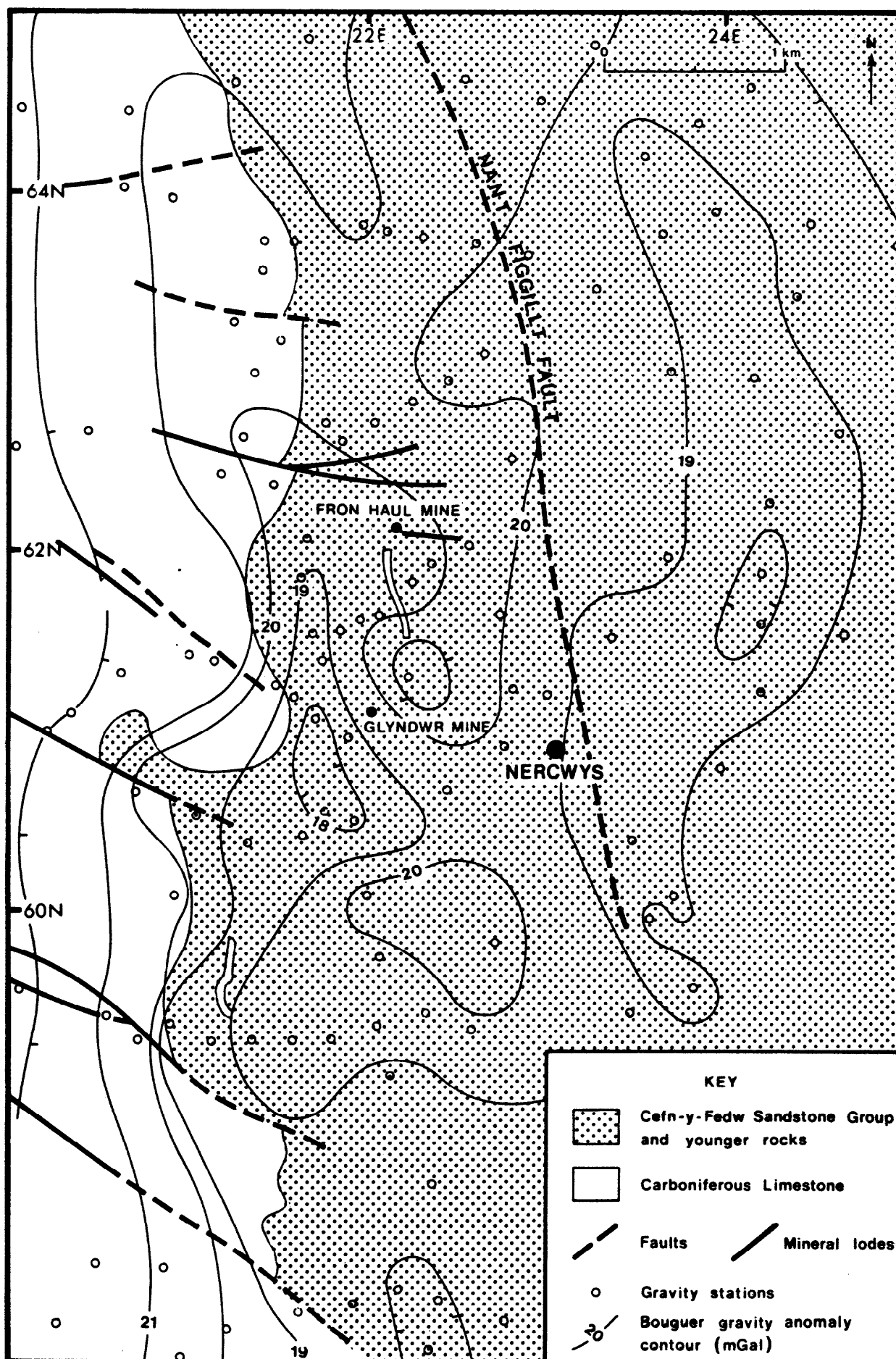


Figure 16 Bouguer anomaly map of the area around Nercwys.

CONCLUSIONS

Four areas in the Halkyn-Minera mining district were selected for exploration using IP and resistivity methods. Possible extensions of known veins and a previously unmapped fault, all largely within the outcrop of the Cefn-y-Fedw Sandstone Group, were sought. No clear indications of mineralisation were discovered. The resistivity results failed to provide unambiguous information on the location of the limestone/sandstone boundary because of the overlap in resistivity values for the two rock types. The resistivities of the Cefn-y-Fedw Sandstone Group are particularly variable and this is considered to be due to variations in the lithologies, the porosities of the sandstones, and the water table. Variations in the porosities and saturation level of the sandstones are considered to be responsible for the observed tendency for the chargeabilities of these rocks to increase with the resistivities.

Evidence from Bouguer gravity anomaly surveys suggests that the outcrop of the Cefn-y-Fedw Sandstone Group north of the Llanelidan Fault is not likely to provide a promising area for exploration. High porosity facies of the sandstones are not considered to be favourable hosts for the mineral veins, and the evidence of rapid down-dip thickening indicates that exploration of the underlying limestones would not be practicable.

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